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GENETICS

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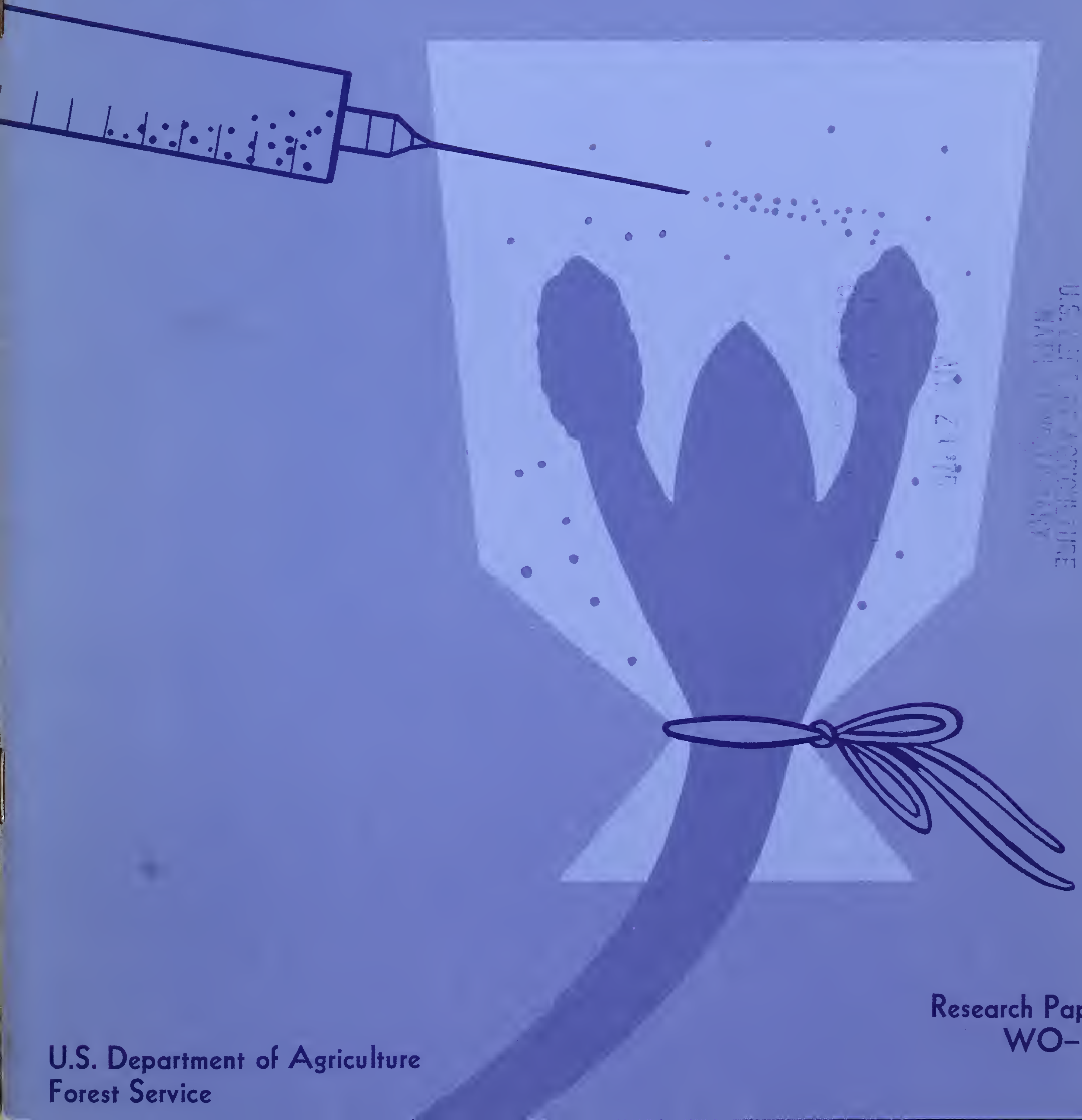
# of BLUE SPRUCE



Research Paper
WO-28

U.S. Department of Agriculture
Forest Service

GENETICS OF BLUE SPRUCE

Reference Abstract

Hanover, J. W.

1975. Genetics of blue spruce. USDA For. Serv. Res. Pap. WO–28, 12 p.

Though research is still in early stages, blue spruce, *Picea pungens* Engelm., appears susceptible to improvement for use as an ornamental, as a Christmas tree, and in shelterbelt plantings. Inter-specific hybridization offers some promise.

OXFORD: 174.7: *Picea pungens:* 165.3, 165.5, 273
KEYWORDS: *Picea pungens*, blue spruce, genetics, tree improvement, ornamental, geographic variation.

Research Summary

RP–WO–28

April 1975

Blue spruce, *Picea pungens* Engelm., reaches sexual maturity late and precociousness is rare. Reproduction phenology presents no unusual difficulties. Techniques for controlled pollination are similar to those for other species. Seeds germinate readily. Several diseases and insects attack the cones, but extent of the damage is not known.

Asexual propagation by rooting, air layering, and tissue culture is possible, but grafting is the most common method.

Blue spruce is relatively slow growing but extremely hardy. Although its range is not extensive, early results of seed-source trials indicate that there is genetic variation in rate of height growth, resistance to frost, and crown diameter. In a controlled environment, rate of seedling growth compares favorably with that of white spruce, *Picea glauca* (Moench) Voss, and hybrids between blue and white and blue and Engelmann spruce (*P. engelmannii* Parry). Extension of the photoperiod greatly accelerates growth of blue spruce and delays dormancy. This technique is useful in the rapid establishment of progeny tests.

Results from 2-year nursery measurements of progenies from throughout the natural range suggests that Arizona, Colorado, and New Mexico sources have the best color development and growth rate.

Genetic variation in foliage color is striking and appears to increase with age. The main cause of blue color is the leaf-surface waxes, which respond to both genetic and environmental factors. Cone characteristics and oleoresin monoterpene composition also show genetic variation.

There are no verified reports of natural interspecific hybrids. Natural hybridization with Engelmann spruce has been suggested, but the artificial hybrid is difficult to make. Blue spruce can readily be crossed with white spruce, and the F_1 hybrids are relatively fast growing.

There is little information about cytology and existence of mutations.

Improvement programs are in progress. Future work should aim at defining important sources of genetic variability, estimating trait inheritance, selecting parents for hybridization and seed orchard establishment, and testing progeny. In addition, much physiological research is needed.

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CONTENTS

Page

INTRODUCTION 1

TAXONOMY 2

SEXUAL REPRODUCTION 2

ASEXUAL REPRODUCTION 4
    Grafting 4
    Rooting 4
    Tissue Culture 4

GENETICS AND BREEDING 4
    Natural Variation and Inheritance 4
        Growth 4
        Foliage Color 5
        Cone and Seed Characteristics 7
        Monoterpenes 7
    Hybridization 10
    Cytology and Mutations 10

IMPROVEMENT PROGRAMS 10

LITERATURE CITED 11

GENETICS OF BLUE SPRUCE

J. W. Hanover[1]

INTRODUCTION

Blue spruce *(Picea pungens* Engelm.) is one of the most commonly planted and highly valued ornamental and shelterbelt tree species in the north-temperate zone (fig. 1). It is used little for timber production, however (Abbott and Eliason 1968), and probably for that reason has not been extensively researched.

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Figure 1.—A typical blue spruce planted as an ornamental.

In its natural range in the southern Rocky Mountains (fig. 2), it grows singly or in small groups along the banks of streams and in broad, open, grassy valleys usually at elevations between 2,000 and 3,000 meters (fig. 3). It may occur in association with the closely related Engelmann spruce, *Picea engelmannii* Parry, although that species is typically subalpine whereas blue spruce is montane. It also occurs occasionally with narrowleaf cottonwood, *Populus angustifolia* James, quaking aspen, *Populus tremuloides* Michx., Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, white fir, *Abies concolor* (Gord. & Glend.) Lindl., subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., and ponderosa pine, *Pinus ponderosa* Laws.

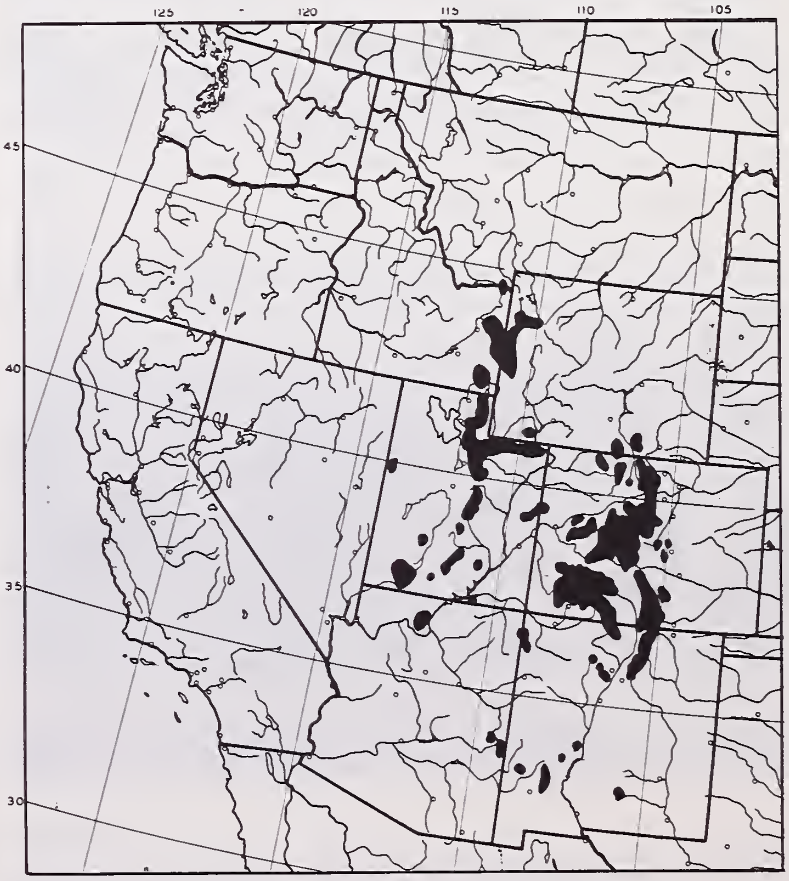

Figure 2.—Natural range of blue spruce.

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TAXONOMY

Of the nine *Picea* species native to North America, six may be grouped into two major complexes on the basis of crossability, distribution pattern, and morphological characteristics. The first complex includes *Picea glauca* (Moench) Voss, *P. engelmanni*, *P. pungens*, and *P. sitchensis* (Bong.) Carr., all of Northwestern America. The second group comprises *P. mariana* (Mill.) B.S.P., which extends from Northeastern United States and Newfoundland westward and northward to Northwestern Alaska, and *P. rubens* Sarg., whose range is in the Northeast (Wright 1955). The three other species, *P. chihuahuana* Martinez, *P. mexicana* Martinez, and *P. breweriana* S. Wats., have extremely small, disjunct ranges, and their taxonomic position in the genus is not yet clear (Nienstaedt and Teich, 1972).

Hills and Ogilvie (1970) suggest that the Northwest American group may have originated from the recently discovered extinct species, *Picea banksii.* According to these authors *P. banksii,* whose fossil remains closely resemble *Picea glauca,* may also be the link between the North American and the more ancient Asian species of spruce.

At least 38 cultivars of blue spruce have been described, all of them asexually propagated (Den Ouden and Boom 1965). They differ in foliage color, tree form, growth habit, and needle morphology. The occurrence of many cultivars suggests that sufficient natural variation exists for genetic improvement through breeding. Studies of natural variation and crossability patterns, however, have been started only recently (Hanover and Wilkinson 1969; Hanover and Reicosky 1972; Fechner and Clark 1969).

SEXUAL REPRODUCTION

Blue spruce is monoecious and normally reaches sexual maturity at about 30 years. Even under cultivation it is late-flowering and precociousness is rare.

Most of the embryological research has been done by G.H. Fechner and coworkers (Fechner 1965, 1973; Kossuth and Fechner 1973). Excellent descriptions of the reproductive cycle of closely related *Picea* species are also given by Mikkola (1969) and others (Miyake 1903; Hakansson 1956). Blue spruce as 12 chromosones (2n=24) (Sax and Sax 1933), and neither natural nor artificial polyploidy or other chromosome irregularities have been reported.

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Figure 3.—Blue spruce of various ages on edge of meadow in the Kaibab National Forest near north edge of Grand Canyon, Ariz. Aspen, Douglas-fir, and white fir are growing in association.

As in white spruce (Rauter and Farrar 1969; Fraser 1962), the primordia of male and female strobili differentiate in late summer of the year preceding fertilization (Fechner 1965) and continue to develop late into the fall. Meiosis occurs in early spring, and the female strobili become receptive about mid-May (fig. 4). The times of receptivity, pollen shed, and subsequent phenological events probably vary with yearly climatic fluctuations, geographic location, and individual tree characteristics.

The female strobili vary in color from white to green to red at the time of receptivity. Male strobili vary from yellowish white to yellow tinged with pink. As color of strobili on a tree is consistent from year to year, this trait appears to be under genetic control.

Fertilization takes place about 4 to 5 weeks after pollination, and embryogenesis progresses until seed and cones mature, which may occur from early September into October depending upon location and yearly fluctuations in weather (Fechner 1965). According to Fechner (1974), maximum germinability is obtained when cones are harvested 4 to 6 weeks before natural seed shed. Cram (1956) recommends harvesting when 90 percent of the cones float on linseed oil. Flotation on turpentine, however, is a more accurate indicator.

In 1970 I analyzed the yield per cone for 318 seed trees throughout the range of blue spruce. Mean number of sound seed per cone was 56, and yields above 100 were not uncommon. Weight varied from 3 to 7 mg per seed. Seeds germinate after 5 to 7 days of warm, moist conditions; there are no prechilling, light, or specific temperature requirements. Seedling loss from damping-off can usually be minimized by not allowing the germination media to become too wet.

Cram's (1966) data from controlled pollinations indicate that intraspecific crossability and self-compatibility vary for individual parents. Forty-seven seed trees, pollinated with five selections, yielded 0.0 to 183 seeds per cone. Self-pollinations of 43 selections yielded 0.0 to 56 seeds per cone.

Cram also noted that seed set varied from year to year on the same trees, although some trees have shown low sets over several seasons. Fechner and Clark (1969) reported failure to set seed in a self-pollination attempt on one blue spruce. Hanover and Wilkinson (1969) selfed one tree and obtained 88 seeds from eight cones, but only two of the seeds were filled and only one germinated. Thus, seeds-per-cone data must be used with caution when evaluating incompatibility in blue spruce.

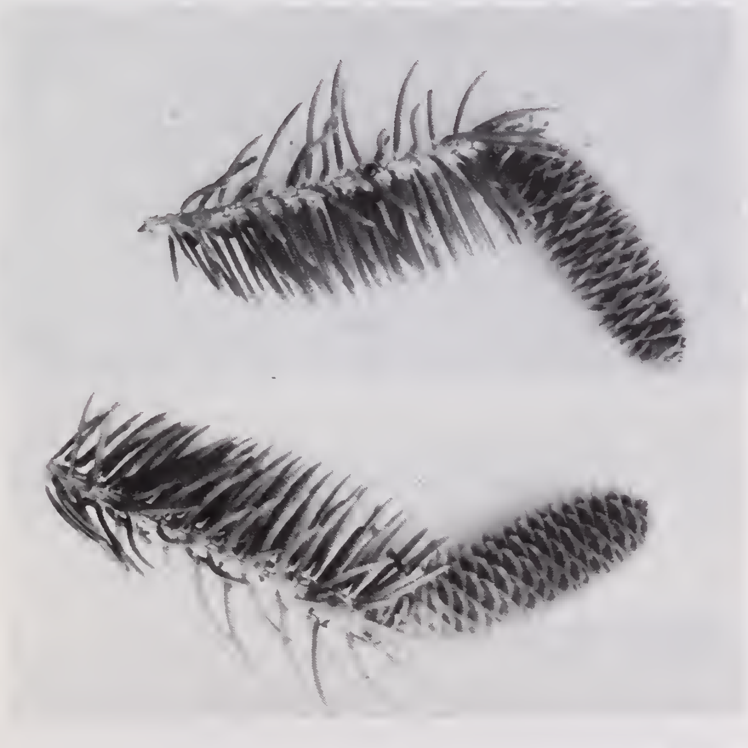

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Figure 4.—Female strobili of blue spruce with scales reflexed at time of pollination.

Techniques for controlled pollination are similar to those used with other conifers. Isolation bags of sausage casing are applied several days before the female strobili are receptive. Pollen is applied with a hypodermic syringe when the scales are fully reflexed. The scales usually close within 1 week, and the pollination bags may then be removed.

Male strobili (pollen catkins) may be picked from branches several days before they would shed naturally and placed in kraft paper bags to dry. The pollen will shed in the bags and can then be filtered through a fine screen funnel. Extracted pollen should be stored dry in closed containers at about 50 percent relative humidity, and at temperatures from just above freezing down to −22°C. Good seed set has been obtained with 1-year-old pollen stored at −22°C. (Hanover and Wilkinson 1969). Fechner and Funsch (1966) reported on pollen stored 11 years at 0 to 4° C.; that held at 50 percent relative humidity showed 29.5 percent germination, in contrast with 0.5 percent germination for storage at 0.0 percent relative humidity. As these and other authors point out, however, *in vitro* tests may not accurately reflect viability *in vivo.* Germination can be tested in 24 hours on a 10-percent sucrose solution at room temperature (Fechner and Funsch 1966).

Cones may be damaged by diseases and insects, although little information is available on actual losses. The rust fungus *Chrysomyxa pirolata* Wint. infects cones and may reduce seed yield and dispersal (Boyce 1961; Nelson and Krebill 1970). Cram (1962) reported severe damage by larvae of the spruce cone moth, *Dioryctria abietella* (D&S). Other insects attacking spruce cones are the moth *Laspeyresia youngana* (Kearf.) and the seed chalcid *Megastigmus piceae* Rohw. (Keen 1952). Female strobili may also be destroyed by the spruce budworm, *Choristoneura fumiferana* (Clem.).

ASEXUAL REPRODUCTION

Grafting

Although blue spruce is easily propagated by seeds, the exceptionally blue or otherwise unique specimens have traditionally been perpetuated by grafting. In commercial practice, scions are usually grafted onto the faster growing Norway spruce, *Picea abies* (L.) Karst., or Sitka spruce (Wells 1953). Grafting is done either in late summer or early spring, with conventional techniques described by Hartmann and Kester (1968). Grafting puts prolonged stress on the plant, and success depends in good part upon the vigor of stock and scion, and upon care after grafting.

Incompatibility of scion and stock in interspecific grafts is apparently not a serious problem. Many specimens of the favorite blue spruce varieties are thriving years after their establishment. But maintenance of an erect stem form may be difficult with grafts.

Rooting

As with most conifers, success in rooting varies with age of the tree from which cuttings are taken. I was able to root 104 of 123 cuttings from trees 1 to 2 feet (30 to 60 cm) in height (fig. 5), but mature-tree cuttings are more difficult (Hartmann and Kester 1968; Clarke 1968). Cuttings taken in late winter or early spring root best. A good procedure is to treat the cut end with a root-inducing hormonal preparation and place it in a well-aerated, moist medium of sand or 1:1 vermiculite and peat mixture. A mist chamber with about 500 foot-candles of supplemental light and 22° C air temperature provides good conditions.

Air layering has not been successful even on young trees. Mergen (1957) reported only 3 percent success with several hundred air layers on 10-year-old trees; with Norway spruce 15 percent of the layers developed roots.

Tissue Culture

The stem cortex tissue has been successfully cultured (Harvey and Grasham 1969; Grasham and Harvey 1970). The work involved the use of callus tissue, and no signs of differentiation appeared during the 120-day test period, but the cultures were healthy and vigorous. Other workers have reported success with related gymnosperms (Steinhart, et. al. 1962; Brown 1967).

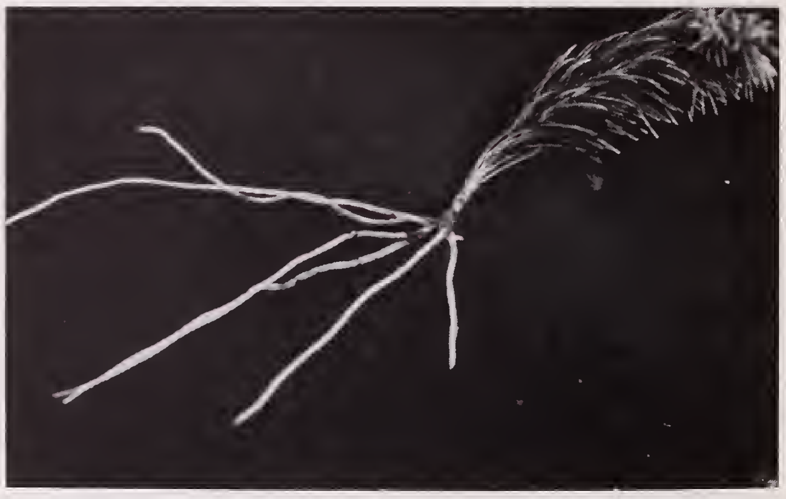

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Figure 5.—Rooted cutting of young blue spruce. At this stage (6–10 weeks) the cuttings are transplanted to soil.

GENETICS AND BREEDING

Natural Variation and Inheritance

Growth

Blue spruce is generally considered to be one of the slowest growing conifers, but little is known about the natural variation in height growth among individual trees or populations. In open-pollinated progenies of 24 selections in Saskatchewan, mean heights at age 13 years varied from 24 to 66 inches (60 to 169 cm), and the correlation between heights at 8 and 13 years was 0.88 (Cram 1961).

Slow growth in the rigorous climates of the prairie regions is substantiated by results from the only seed-source trial undertaken until just recently (Dawson and Rudolf 1966). Seven seedlots obtained from stands in Colorado, Arizona, Utah, and Wyoming were grown in Denbigh, N.D. At age 13, after 5 years in the field, mean seedlot height varied from 14 to 23 inches (36 to 58 cm). Because few sources were included and growing conditions were poor throughout the test period, the amount of geographic variation could not be estimated. One seedlot from the Wyoming-Utah border exceeded the other six in survival, height growth, resistance to frost damage, and crown diameter.

Apical growth is under photoperiodic control. Cram and Lindquist (1963) reported continuous growth of seedlings given a 16-hour photoperiod. I have compared growth of several species and hybrids under continuous light; blue spruce grew relatively well, but at a significantly slower rate than black spruce (table 1). I have not been able to stimulate continuous growth on grafts which are physiologically mature—an indication that the effect of extended photoperiods in delaying dormancy may change with age of the tree.

In 1969 I obtained more than 400 seedlots of blue and Engelmann spruce from 75 populations throughout the natural ranges (fig. 6). Seed from 238 lots representing 50 populations was sown in a replicated test in the greenhouse, and the seedlings were grown for 6 months under accelerated conditions including continuous light (Hanover and Reicosky 1972). Blue spruce attained remarkable height growth, and significant differences were detected between individual progenies and populations (table 2). After the greenhouse phase was completed, the seedlings were put into permanent genetic test plantations for long-term observation. Survival after outplanting (done by machine) has been greater than 90 percent. By age 3 years, many of the seedlings had attained heights of 28 inches (70 cm).

Seedlings grown from the same seedlots in a nursery at East Lansing, Mich., also showed genetic variation in height growth after 2 years (table 3). Under the more natural outdoor conditions and longer time interval, however, both progeny and population variances were higher than in the greenhouse test. The nursery data indicated that seedlings from Colorado, New Mexico, and Arizona grow more rapidly than those from Utah, Wyoming, or Montana. Comparison of the greenhouse and nursery data for height growth indicates that there is not a close correspondence in progeny or population rankings for the two growing conditions.

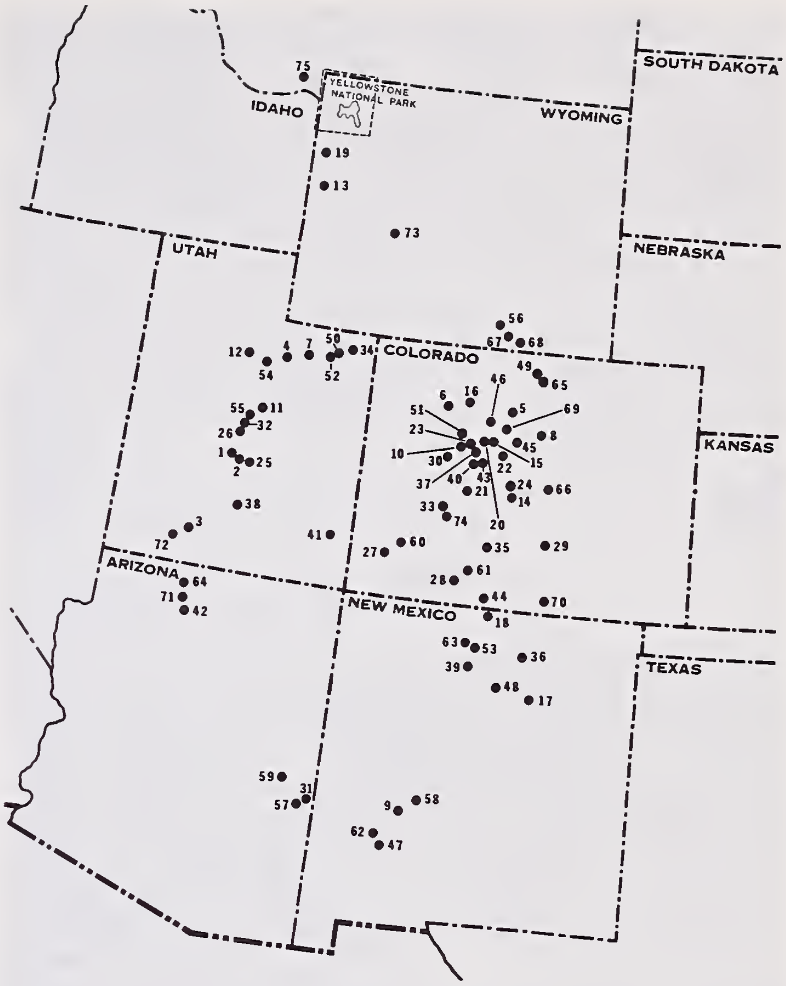

Figure 6.—Populations of blue and Engelmann spruces from which cones and seeds were collected in a rangewide progeny test.

Foliage Color

The blue foliage coloration that makes this species prized as an ornamental resides in the waxes deposited on the surface of the needles. With a scanning electron microscope, Hanover and Reicosky (1971) have described some of the variability in physical characteristics of these waxes (figs. 7 and 8); both the quantity of surface wax and its physical structure are important in determining foliage color. The waxes also cause much stomatal occlusion in this and other conifers (fig. 8). The adaptive significance of these observations remains to be seen.

Genetic variation in foliage color is striking. Individual trees vary from pure green to steel blue.

TABLE 1.—*Mean heights in cm for 3 species and 2 hybrids grown under continuous light.*

Age of seedlings	*P. glauca*	*P. pungens*	*P. mariana*	*P. glauca* × *P. pungens*	*P. glauca* × *P. engelmannii*
16 weeks	10.0	9.0	12.8**	9.3	10.0
19 weeks	12.2	11.1	16.3**	11.5	12.8
22 weeks	14.6	14.0	21.7**	14.2	15.6
25 weeks	15.6	14.8	25.3**	15.0	16.4
28 weeks	16.0	15.2	27.9**	15.5	16.9

**Differs significantly (0.01 level) from all other progeny groups.

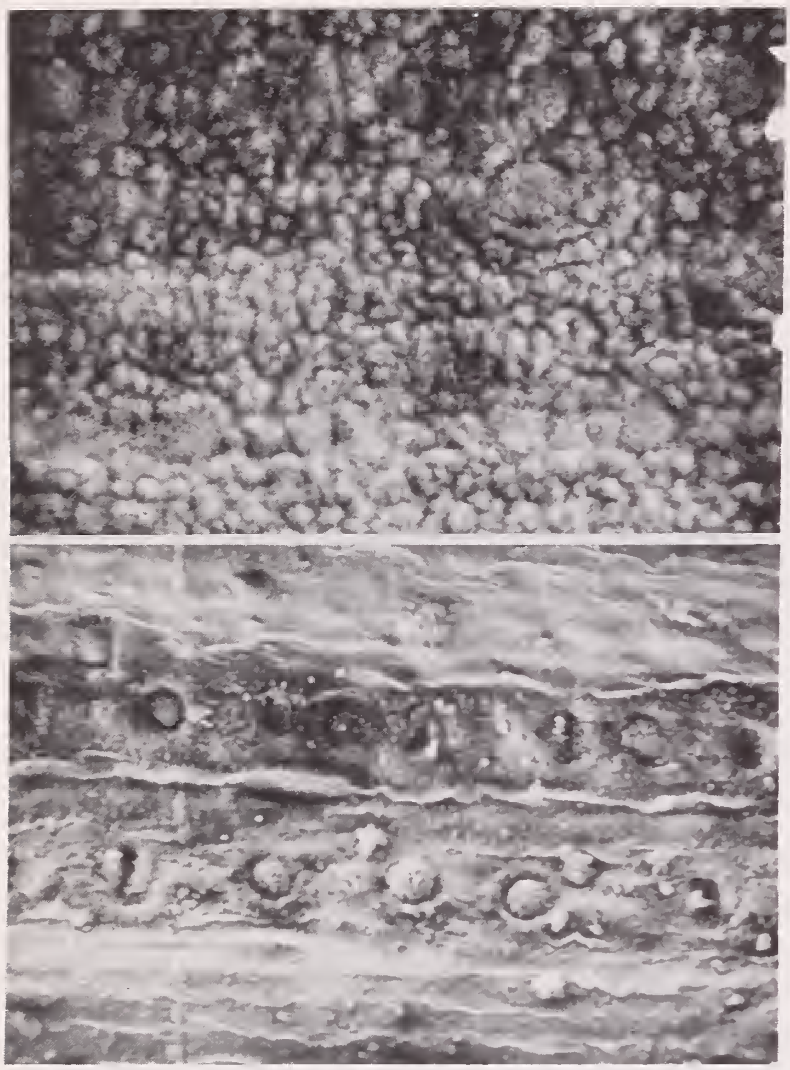

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Figure 7.—Scanning electron micrographs of blue spruce needles. *Above:* A glaucous needle with heavy epicutular wax and obscured stomates. Figure 8, bottom view, shows the same needle without surface wax. *Below:* Needle of a nonglaucous blue spruce, × 200.

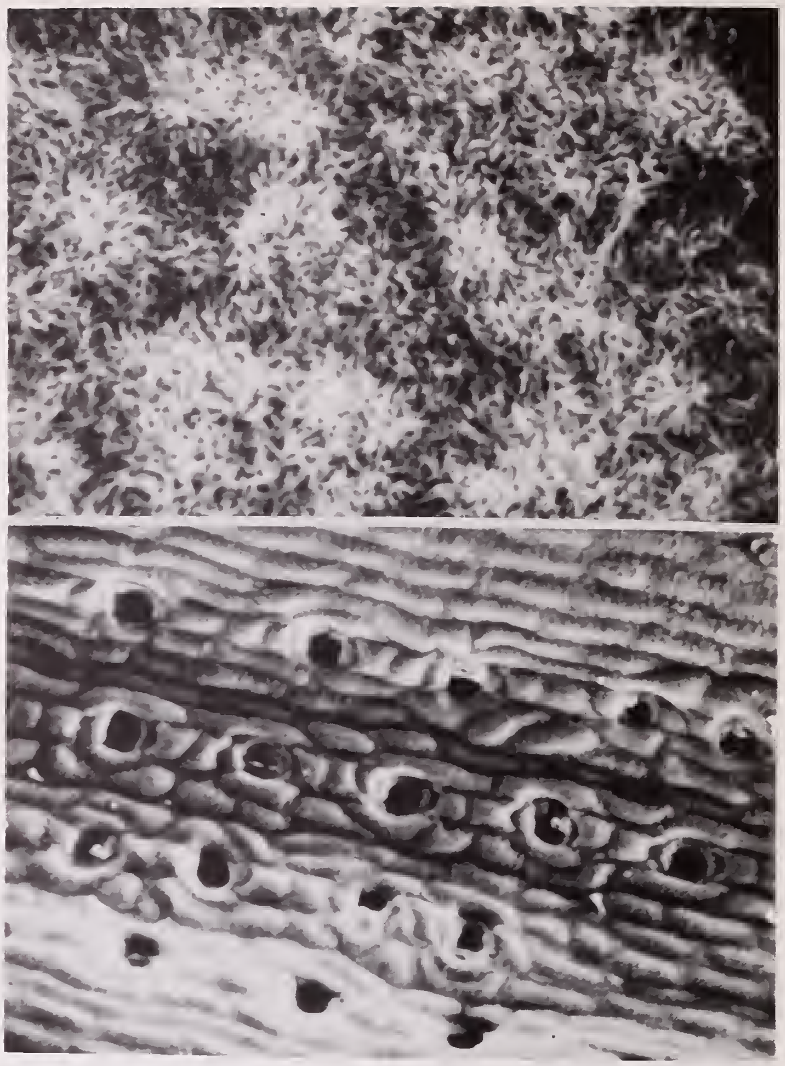

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Figure 8.—Scanning electron micrographs of needles of a glaucous blue spruce, showing *(above)* surface wax structure, × 1000, and *(below)* needle surface after rinsing in ether, × 200.

TABLE 2.—Mean total heights of the 10 tallest open-pollinated progenies and the 10 tallest populations of blue spruce 6 months after sowing in the greenhouse (Hanover and Reicosky 1972)

Progeny number	State of origin	6-month height	Population number[1]	State of origin	6-month height
		Cm			*cm*
53	Colorado	38.2	63[2]	New Mexico	29.9
311	Utah	37.0	30	Colorado	26.4
23	Colorado	35.5	26	Utah	26.0
161	Colorado	35.3	6	Colorado	26.0
204	Utah	34.8	4	Utah	25.8
149	Utah	33.5	10	Colorado	25.1
14	Utah	33.2	27	Colorado	25.0
13	Utah	32.6	55	Utah	24.2
67	Utah	32.5	12	Utah	24.1
26	Colorado	32.2	13	Wyoming	23.8
Mean of all progeny:		22.1 ± 5.1			22.1 ± 0.24
F-value =		2.21[3] (n=238)			3.89[3] (n=61)

[1] Numbers correspond to those in figure 6.
[2] This population is predominantly Engelmann spruce.
[3] Significant at the 0.01 level.

TABLE 3.—Mean total heights of the 10 tallest open-pollinated progenies and the 10 tallest populations of blue spruce after 2 years in the nursery.

Progeny number	State of origin	2-year height	Population number[1]	State of origin	2-year height
		Cm			*cm*
163	Colorado	20.6	27	Colorado	18.8
162	Colorado	19.7	57	Arizona	18.4
193	Arizona	19.3	31	Arizona	17.6
192	Arizona	19.2	28	Colorado	17.2
198	Arizona	19.2	33	Colorado	16.6
203	Arizona	19.0	48	New Mexico	16.5
348[2]	Arizona	18.9	53	New Mexico	16.3
55	Colorado	18.8	30	Colorado	16.1
197	Arizona	18.8	47	New Mexico	16.1
201	Arizona	18.7	9	New Mexico	16.1
Mean of all progeny:		13.8 ± 0.40			13.8 ± 0.98
F-value =		5.08[3] (n=258)			9.28[3] (n=55)

[1] See figure 6.

[2] These progeny are Engelmann spruce.

[3] Significant at the 0.01 probability level.

Certain seed sources, notably the Kaibab National Forest in Arizona, are preferred by nurserymen as yielding a high frequency of blue trees. The seed-source studies needed to define the variation in this trait are too recent to yield definitive results, but early indications from 2-year-old seedlings in our nursery study are that the incidence of blueness is much higher in the sources from Arizona and New Mexico than in those from other areas. It is also apparent, however, that foliage color differences are minimal in very young seedlings and increase with age. Cram (1968) states that needle color in Saskatchewan becomes stable only after 10 to 12 years of growth. Moisture and nutritional conditions may obscure or accentuate genetic differences in the ability of seedlings to produce the leaf surface waxes and show blue color.

The inheritance mechanism is apparently not a simple one (Cram 1968). Controlled pollinations made over several years and with many local selections have resulted in the designation of a few parents with ability to transmit blue color to as much as 50 percent of their progeny. Number and kinds of genetic factors have not been resolved.

Cone and Seed Characteristics

From analysis of cone and needle characteristics of blue and Engelmann spruces from 21 locations in western United States, Daubenmire (1972) concluded that these species do not hybridize when they occur together, but he found no one characteristic that could be used to distinguish between them.

I studied 61 parental populations of blue and Engelmann spruce from the range-wide test and found that a significant variation (0.01 level) exists between populations for the traits listed here:

Parental trait	*F-value*
Foliage color	4.07
Seed weight	3.31
Sound seed/cone	5.04
Cone length	6.41
Cone width	2.11
Cone scale length	4.04
Cone scale width	3.08
Cone scale margin	4.69
Cone scale shape	2.43

Figure 9 illustrates the range of variation in cone and cone scale features for representative individual trees from these populations. There is continuous intergradation between blue and Engelman spruces for these traits. A multivariate analysis (h-group analysis) of 10 parental cone and seed characters showed that the 61 populations fall into three groups (fig. 10). Group 3 (A, B, C, and D) is nearly all typical Engelmann spruce, group 2 (E and F) is typical blue spruce, and group 1 (G, H, I, and J) consists of intermediate types that were variously identified at collection time as blue spruce, Engelmann spruce, a hybrid, or a mixture of the two species. Thus, on the basis of these data, Daubenmire's (1972) study, and my field observations, the two species are often indistinguishable.

Monoterpenes

There is some evidence that chemical genetic variation exists among individual trees. Rottink and I (1972) analyzed oleoresin monoterpenes from

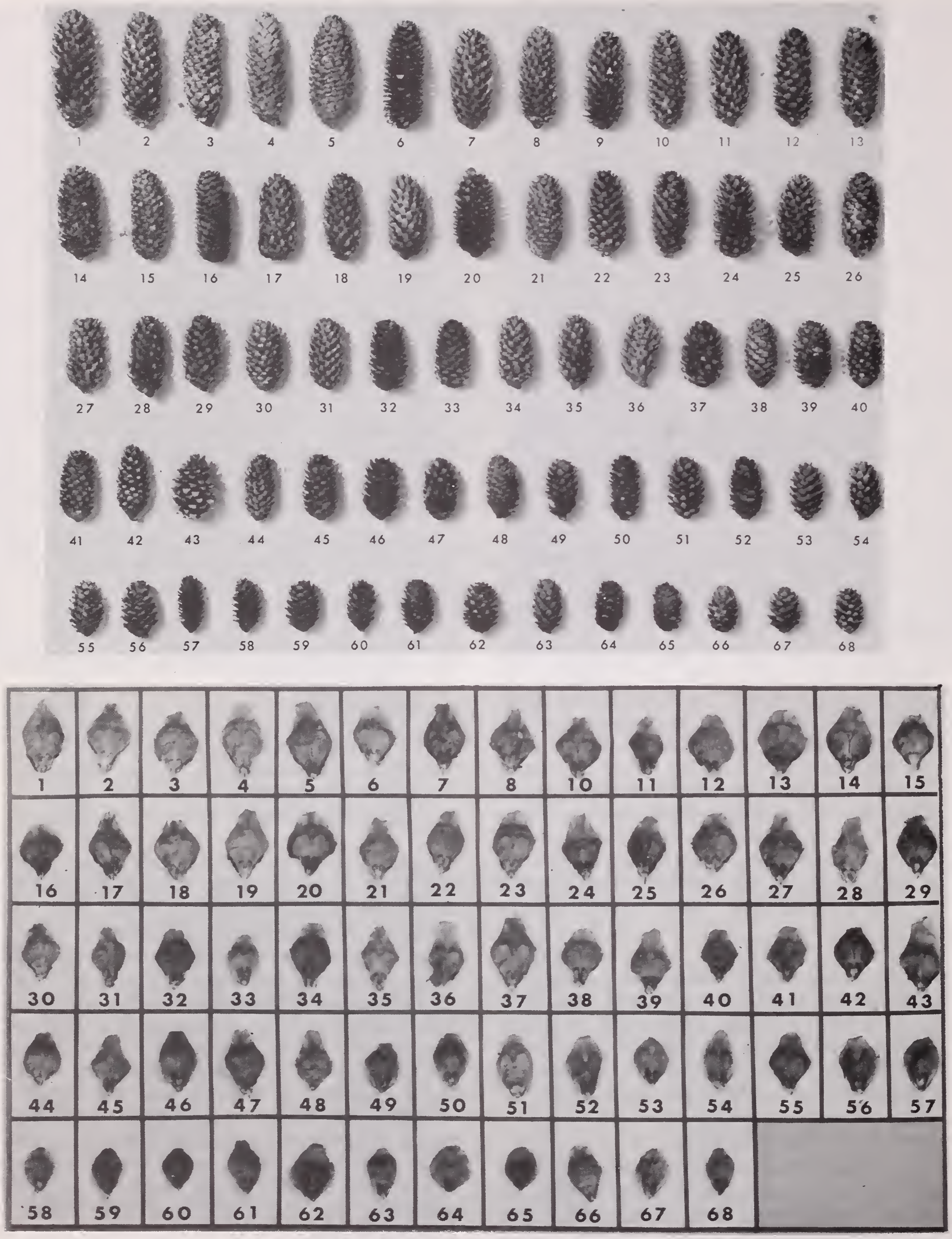

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Figure 9.—Variation in cones *(above)* and their respective scales *(below)* among individual parent trees throughout the natural range of blue spruce. The numbers match scales to their cones but do not refer to the populations mapped in fig. 6. The upper rows are predominantly blue spruce and the lower rows Engelmann spruce.

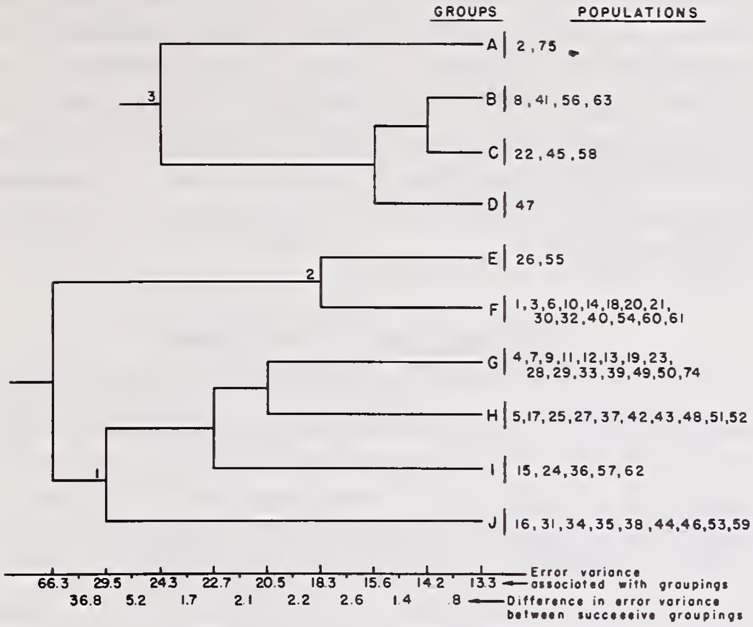

Figure 10.—Results of a multivariate analysis of 10 parental cone and seed characteristics of the blue and Engelmann spruce populations. The most natural grouping of populations is that associated with the largest difference in error variance between successive groupings, i.e., 3 groups: designated 1 (G, H, I, J), 2 (E and F), and 3 (A, B, C, D).

11 cultivated, grafted varieties of blue spruce distributed by commercial nurseries. Our object was to determine the feasibility of differentiating varieties whose identity had been lost. The results showed that monoterpene contents permitted at least tentative identification (table 4).

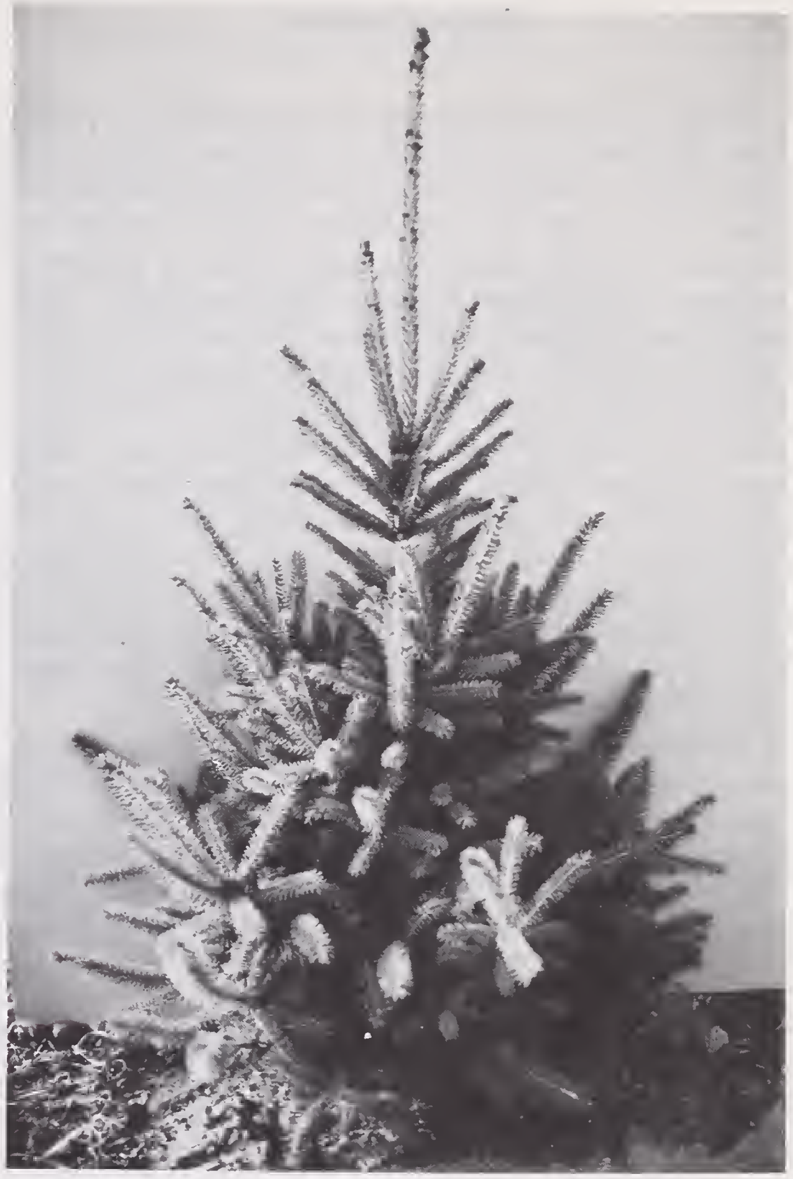

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Figure 11.—A typical white × blue spruce hybrid. At age 3 years it is 31 inches (79 cm) in height.

TABLE 4.—Mean composition (as percent of oleoresin) of monoterpenes of 10 blue spruce cultivars[1]

Cultivar	No. of trees sampled	α–Pinene	Camphene	β–Pinene	Myrcene	3–Carene	Limonene	Terpinolene	Total monoterpenes
Argentea	6	12.7ab	0.4a	5.7a	0.8bc	2.5cd	2.7cd	0.4bc	25.2a
Compacta Thume	4	11.3bc	.3a	5.4ab	.7c	1.7d	1.3d	.6abc[2]	21.4a
Globosa	4	13.6ab	.4a	5.2ab	.9abc	2.0cd	1.6d	.5bc	24.1a
Hoopsii	5	8.8c	.3a	3.8ab	.9abc	7.3a	4.7ab	1.0a	26.8a
Hunnewelliana	8	12.7ab	.4a	5.1ab	.8bc	2.4cd	1.6d	.6bc[2]	23.5a
Koster	4	9.6bc	.4a	4.4ab	1.0abc	2.7cd	5.8a	.8ab	24.6a
Mission Blue	4	10.0bc	.3a	4.9ab	.8bc	2.6cd	3.8bc	.4bc	22.8a
Moerheimi	5	15.9a	.5a	3.9ab	1.2a	.7d	3.9bc	.3c	26.4a
Pendula	4	10.4bc	.2a	3.9ab	.7c	6.3ab	2.5cd	.8ab	24.8a
Thomsen	5	10.8bc	.3a	3.4b	1.1ab	4.4bc	5.7a	.7abc	26.4a

[1] For a given monoterpene, cultivarietal means not followed by a common letter are statistically different from one another at the 0.05 level as determined by Tukey's significant-difference test (ω-procedure).

[2] Differences in sample size result in 0.6 being statistically different from 1.0 in one case and not in another.

Hybridization

Only a limited amount of interspecific hybridization has been attempted with blue spruce, and there are no verified reports of natural hybridization with other species. From field observations, several workers have suggested that a degree of natural hybridization may occur between blue spruce and Engelmann spruce (Weber 1953; Porter 1957; Habeck and Weaver 1969). Putative hybrids between *Picea glauca* and *P. pungens* were mentioned by Santamour (1967), Safford et al. (1969), and Tsitsin (1960). This cross has been made successfully in both directions by Hanover and Wilkinson (1969), and the hybridity has been documented. From early indications the blue × white hybrid (fig. 11) has good growth rate (table 1) and possesses several other desirable attributes of both species.

Fechner and Clark (1969) attempted the *P. pungens* × *engelmannii* hybrid artificially. They obtained only 1 to 2 percent viable seed when Engelmann spruce was the female parent and no viable seed from the reciprocal cross. Their trials were made with a single tree of each species, and attempts with more parental combinations are needed. Kossuth and Fechner (1973) showed that reproductive failure in this cross occurred at several stages prior to formation of the embryo.

Other apparently successful artificial hybridization attempts include *P. engelmannii* × *pungens* (Santamour 1967) and *P. mariana* × *pungens* (Jeffers 1971).

Cytology and Mutations

No cytological investigations of blue spruce have been made. I have noted a few mutants. Several mother trees used as selections for controlled pollination yield albino seedings in 3:1 ratios, an indication that this mutant gene is rather frequent in blue spruce, as it is in other conifers. Another mutation-like condition is dwarfism of seedlings from certain parents in the interspecific cross between blue and white spruce. Thirty-four dwarfs and 12 normal seedlings resulted from one set of parents. This distribution suggests a simple Mendelian inheritance that is expressed only in the cross. I have also observed one mature blue spruce with pure yellow pollen catkins in contrast to the normal red- or green-tinged strobili.

IMPROVEMENT PROGRAMS

Since it is unlikely that blue spruce will be grown in quantity for its wood, genetic improvment programs will focus on its values as an ornamental, for shelterbelt plantings, and as a Christmas tree. The traits most likely to be emphasized are juvenile growth rate, blue foliage color, early flowering, and needle bluntness. Because it possesses a unique combination of qualities including pyramidal form and fullness, long needle retention time, and resistance to damage from cold, drought, salt spray, and most pests, interspecific hybrids should be included in improvement plans.

The first improvement work was undertaken in 1954 by Cram in Saskatchewan. His objective was to develop techniques for mass producing, from seed, blue trees for shelterbelt use (Cram 1969). Although parental selections were local trees, controlled pollinations and 10 or more years of observations on hybrid progenies yielded one cross that gave up to 60 percent "intense blue" seedlings. The two seed trees of the superior combination have been grafted for a natural crossing block to mass-produce hybrid seed.

In 1958 the USDA Forest Service, in cooperation with the University of Minnesota, began the small seed-source trial discussed earlier. The progeny from seven collections are growing in Denbigh, N. Dak., but at a very slow rate even for that location. From this and other experiences, two procedural techniques are suggested for improvement programs with blue spruce. First, to accelerate juvenile growth, initial progeny tests should be conducted in less harsh climates than are natural for the species, or under controlled environmental conditions. Seed orchards and breeding arboreta should also be established under conditions favoring early flowering. Second, every effort should be made to improve the growing conditions in test plantations established within the natural range. Weed control, cultivation, fertilization, and irrigation may all be necessary.

The most recent improvement program is the comprehensive one begun at Michigan State University in 1968 and referred to earlier. This work includes range-wide open-pollinated seed collections; progeny-testing both within and outside the natural range; selection in the nursery, plantation, and in natural stands; and both intraspecific and interspecific hybridization. No seed-orchard work has begun yet in Michigan.

Future efforts towards genetic improvement of the species will probably concentrate on: (1) definition of major sources of genetic variation for important traits; (2) estimation of heritabilities for the traits; (3) selection of parents for hybridization and seed-orchard establishment; (4) testing of progenies for general adaptability and specific performance in various regions.

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This publication is one in a series on the genetics of important forest trees of North America being published by the Forest Service, U.S. Department of Agriculture, in cooperation with the Society of American Foresters. Development of this series is in accord with the resolutions of the World Consultation on Forest Genetics and Tree Improvement at Stockholm in 1963 and the Second World Consultation on Forest Tree Breeding at Washington, D.C., in 1969. The Committee on Forest Tree Improvement of the Society of American Foresters undertook the preparation of manuscripts for North American species.

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